TITLE: LARGE AREA SMART PIEZOELECTRIC AND PYROELECTRIC SENSORS

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EIGHTH INTERIM REPORT

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1. Introduction

In the seventh interim report an account was provided of the embedment of a composite transducer within a reinforced epoxy laminate structure for use as an in-situ acoustic emission (AE) sensor, strain gauge or ultrasonic detector/transmitter for NDT techniques.

The present report is concerned with the further investigation of the suitability of these composite materials as both surface mounted and embedded AE sensors. Particular attention has been focused on the detection on acoustic waves in structures which possess plate-like geometry where the propagation of acoustic waves are constrained to definite modes.

2. Acoustic Emission and Plate Waves

Acoustic emission as briefly described in the seventh interim report is the elastic energy that is spontaneously released by materials when they undergo deformation. An acoustic emission sensor is used to detect the dynamic motion resulting from the AE events and to convert the detected motion into an electrical signal. Most commercially available AE sensors are used to detect the motion of the surface of the material at a point some distance from the source of the emission. The signal at this point will have been altered in some form due to the geometry's and properties of the structure concerned. When considering structures with plate like geometry, i.e. two dimensions much larger than the third, the propagation of the elastic waves will be governed by Lamb's Homogeneous equations ([1], and references therein). When the wavelength of the elastic wave is much larger than the thickness of the plate the set of governing equations are greatly simplified. In the 'thin plate' region equations derived from the classical plate theory can be used to understand the propagation of acoustic waves.

Plate waves in aluminium plates have been investigated previously [1-3]. It was found that the acoustic waves in the plate propagated in two distinct modes, the extensional and the flexural mode. The extensional modes have higher velocities than the flexural mode and frequencies predominantly above 300kHz as compared to those of the flexural mode with frequencies predominantly less than 300kHz. The higher frequencies of the extensional mode suffer from greater attenuation than the flexural mode. AE measurements typically concentrate on threshold measurement for triggering of the detection electronics and location detection of source. When plate waves

are present the mismatch in velocities will cause the extensional mode to arrive earlier than the flexural mode. This is fine if all the transducers are triggered by this mode. But due to the greater attenuation of the higher frequencies present, this may not be the case. The flexural mode, while having a greater amplitude perpendicular to the plane of the plate, is a dispersive mode. Therefore inherent errors will occur if this mode is used to detect the location of the source.

Detection of the whole of the AE signal without corruption by the transducer will yield a signal containing the separated modes and their relevant frequencies. The use of all the information contained within the signal could be used to accurately locate the source.

3. Fabrication of Composite AE transducers

The preparation of ceramic/polymer composite thin films has been discussed in the first and second interim report on 'large area smart piezoelectric and pyroelectric sensors'. The construction of a surface mounted transducer incorporating the composite thin films consists of a grounded stainless steel case, an epoxy-tungsten backing for the electroactive film and connections to the two electrodes as shown in figure 1.

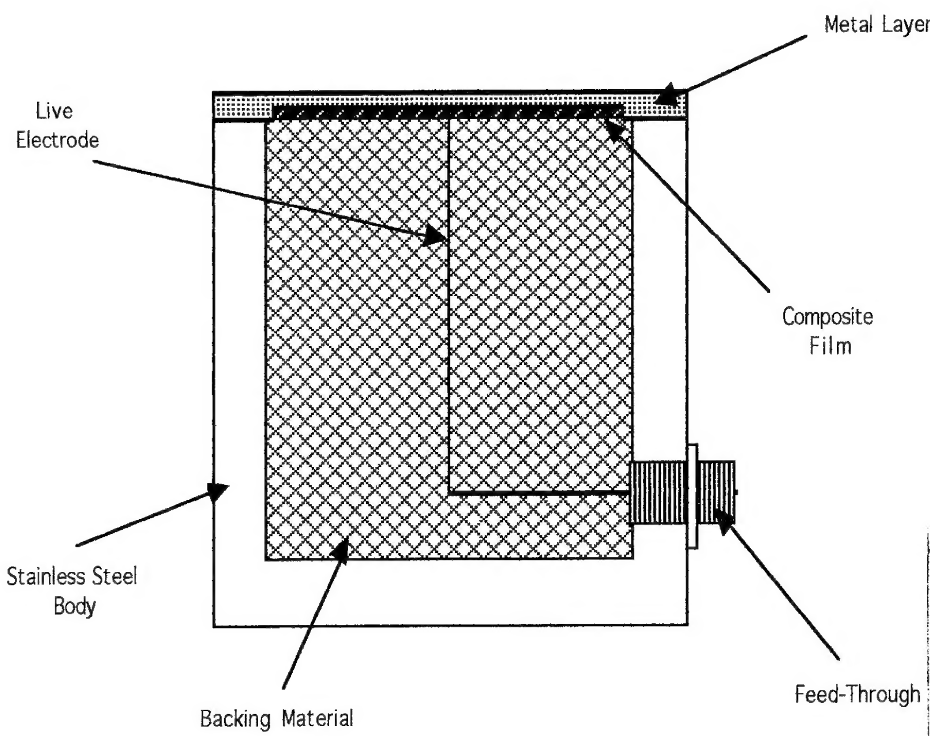

Figure 1: Composite film surface mounted transducer.

The epoxy-tungsten backing material consists of tungsten powder with grain size range of 25-250μm dispersed in an epoxy matrix. The backing material is ideally chosen so as to have the same acoustic impedance as the electroactive material to eliminate reflections from the backing/composite film boundary and hence allow the acoustic wave to propagate into the backing material. The backing material should also exhibit high losses so that the sound wave is attenuated to a negligible value before the reflected wave from the back of the backing reaches the piezoelectric material. The composite properties of the chosen backing material exhibit high losses.

Impedance's measurements of the composite films were carried out as described in the third interim report. These measurements are used to evaluate the acoustic impedance's (Z_a) of the films, the resonant frequencies (f_o) and their electromechanical coupling coefficients (k_t). The composite films used in this work to produce transducers have average values of Za = 17 MRayls, fo = 20 MHz and kt = 0.22.

The backing material used contained a tungsten volume fraction of approximately 35% corresponding to a specific acoustic impedance of around 12 MRayl. This was close to the maximum loading permitted by this mixture. The piezoelectric film was bonded to the backing material by use of a conductive epoxy (Electrodag 938, Acheson Colloids Company) to ensure electrical connection to the live electrode. The thickness of this bonding layer was kept as thin as possible and ideally, should be less than one hundredth of the wavelength at the resonant frequency in order for the bonding layer to be transparent to the acoustic wave [4]. The upper face of the piezoelectric film was aluminium evaporated in order to make contact to the grounded case.

The fabrication of an embedded composite film transducer was described in the seventh interim report.

4. Face-to-Face Method

The frequency response of two commercial transducers and two ceramic/polymer transducers were evaluated using a face-to-face method where two AE transducers are coupled with their sensing faces together as in figure 2. Silicone vacuum grease was used to ensure the transducers were acoustically coupled. One of the transducers was used as a driving transducer while the other was used as a sensing transducer and the output of the second

transducer was recorded on a storage oscilloscope [Gould 4050] at a sampling rate of 2MHz.

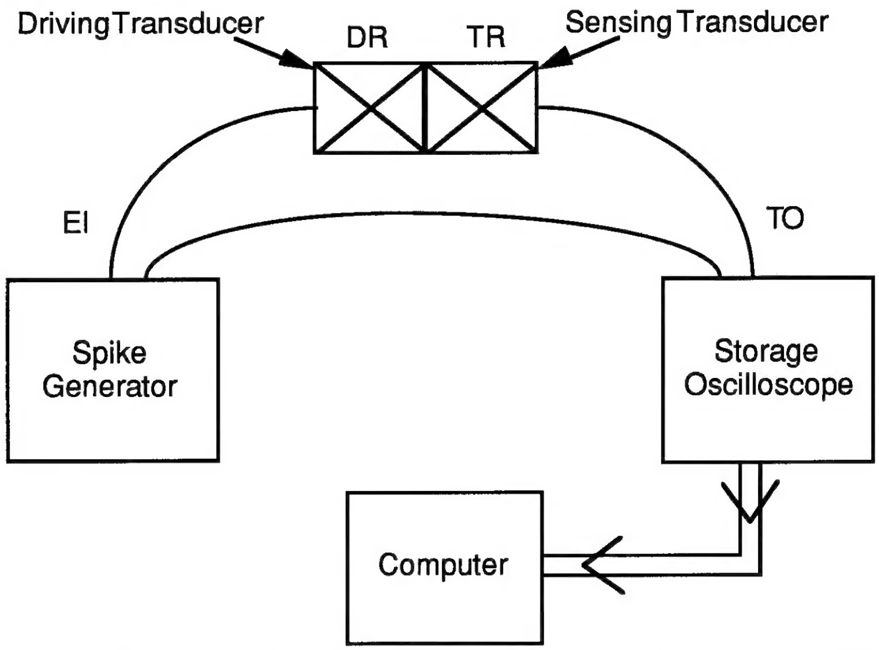

Figure 2: Face-to-face method for evaluating the relative frequency response of an unknown transducer.

Assuming that the attenuation due to the coupling interface is negligible the output of the sensing transducer (TO) will be a convolution ($\otimes$) of the electrical input signal (EI), the response of the driving transducer (DR), the response of the sensing transducer (TR) and the response of the detection electronics (DE) such that

$$TO = EI \otimes DR \otimes TR \otimes DE \qquad ...(1)$$

In the frequency domain the convolution of the responses becomes a straight multiplication so

$$TO(f) = EI(f) \times DR(f) \times TR(f) \times DE(f) \qquad ...(2)$$

Assumptions can be made that $DE(f)$ is flat and equal to unity over the range of frequencies we are concerned with and that the transducer responses are reversible, i.e. input response is equal to the output response.

If the two transducers are of the same type then the driving response (DR) can be evaluated from

$$TO(f) = EI(f) \times [DR(f)]^2 \qquad ...(3)$$

$$\therefore DR(f) = \sqrt{\frac{TO(f)}{EI(f)}} \qquad ...(4)$$

Once *DR* has been determined then the response of another transducer can be found from

$$TR(f) = \frac{TO(f)}{EI(f) \times DR(f)} \qquad ...(5)$$

The electrical drive signal applied to the driving transducer was produced by a 150V spike generator [Par Scientific Instruments SPIKE 150 PR] which produced a spike of rise time 90ns and duration 280ns. The spike generator provides an output suitable for connection to an oscilloscope with an amplitude of approximately 3V. The linear scaling factor of this output to the main output was unknown. This output of the generator was used for the frequency analysis of the electrical input. Fast Fourier Transform (FFT) analysis was used to provide the frequency components over the range 0 - 1MHz.

The frequency spectrum of all the signals produced by the transducers and the spike generator were produced by discrete Fast Fourier Analysis on the recorded signals. The analysis was done using the computer program Matlab which has built in functions for discrete analysis of waveforms.

Two identical transducers [Dunegan/Endveco S 140 B/HS] were used to evaluate their responses. The reversibility of the responses was checked by driving the transducers in both directions and comparing the outputs. One of these transducers was then used to provide a driving transducer with known response to evaluate the ceramic/polymer transducers compared to two widely used commercially available transducers [Dunegan/Endveco S 140 B/HS and Physical Acoustics Corp. R15]. It is noted here that the characterisation of the transducers are not an absolute characterisation but a comparative one. Due to this fact the responses of the transducers discussed here are normalised to the output of the driving transducer.

The responses of a commercial transducers and an average response of a surface mounted ceramic/polymer transducer, both normalised to the response of the driving transducer, are shown in figures 3 & 4.

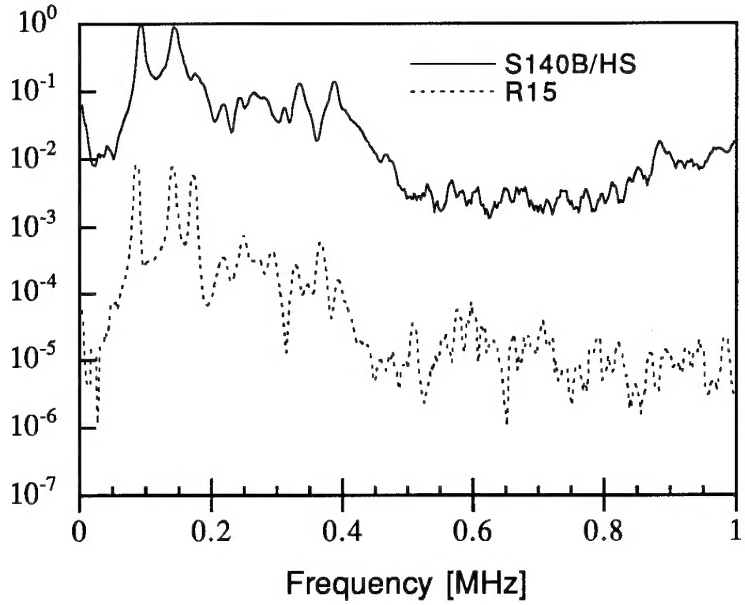

Figure 3: Normalised response of the driving transducer [Dunegan/Endveco S 140 B/HS] and the normalised response of another commercially available resonant transducer [PAC R15].

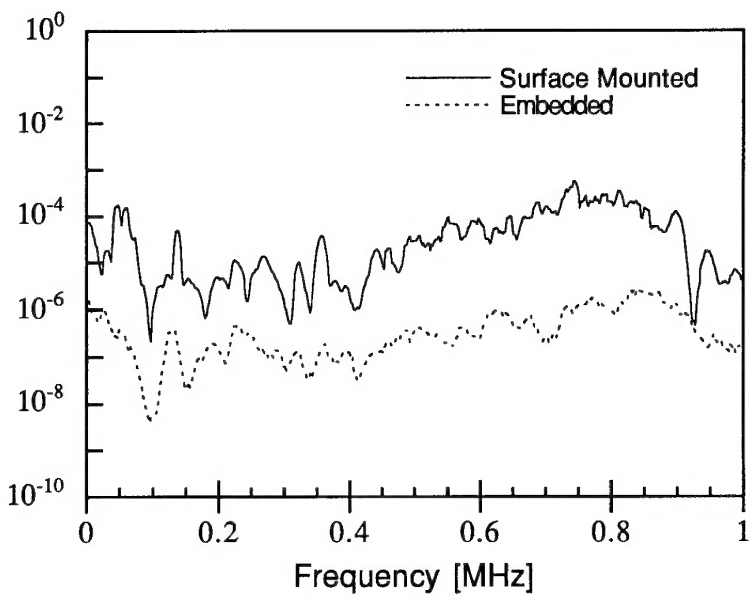

Figure 4: Normalised responses of ceramic/polymer surface mounted and embedded transducers. Greater attenuation of the signal from the embedded transducer is present due to the nature of the epoxy plate.

It can be seen from these figures that although the ceramic/polymer transducer is considerably less sensitive than the commercially produced ceramic transducers it possesses a relatively flat response over the frequency range 0 to 1MHz, showing it to be viable for the detection of acoustic waves with these frequencies.

A thin sensor film [~100μm] of PTCa(24mol% Ca)/P(VDF-TrFE)(75mol% VDF) 65/35vol% was embedded into a test piece of glass fibre reinforced epoxy plate with electrical connections to the edge of the plate. The driving transducer was then placed on the surface of the plate and excited in the same manner as the face-to-face method. The output of the embedded transducer was then digitised and analysed as before. Figure 4 shows the response of the embedded sensor.

Again the embedded sensor is less sensitive than the commercially available sensors. A wide band flat response is noted. It should also be noted that this preliminary investigation of an embedded sensor is neither an absolute measurement nor a relative one. Due to the nature of the epoxy plate greater attenuation of the signal, as compared to the face-to-face method, is present showing the embedded transducer to be less sensitive than it appears to be in practice.

The suitability of the ceramic/polymer sensor for detecting plate waves in aluminium plates was investigated and compared to a commercially available transducer. The sensors were mounted on the surface of an aluminium plate using silicone vacuum grease to ensure an acoustic coupling between the plate and the transducer. An acoustic emission source was simulated by breaking of a pencil lead [Pentel 0.5mm 2H] on the surface of the plate a distance of 127mm from the sensing transducer. The output of the sensing transducer was directly recorded, without amplification, on a digital oscilloscope at a sampling rate of 20MHz. Care was taken not to record signals corrupted by reflections from the edges of the plates.

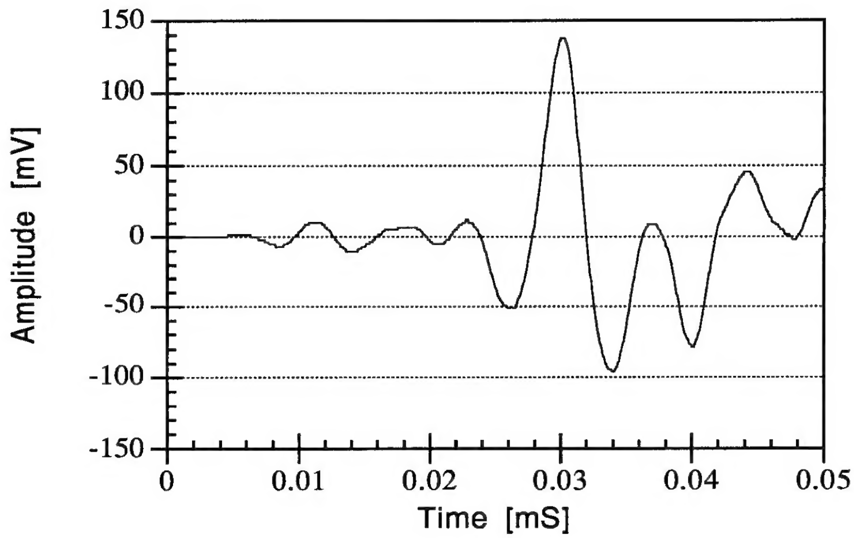

Figure 5: Response of a PAC R15 AE sensor to a lead break 127mm away on an aluminium thin plate.

Figures 5 & 6 show the plate waves detected by the commercial sensor and the ceramic/polymer sensor respectively. The extensional mode and the flexural mode of the waves can be seen clearly from both of these figures. The resonant frequency of the commercial transducer of 150kHz is present in both the extensional and the flexural mode of the transducer output thus masking the other vibrational frequencies present in the plate, while the signal produced by the ceramic/polymer transducer showed a distinct difference in modal frequencies. This ability to discern the difference in frequency from mode to mode exhibits the wideband nature of the composite transducing element.

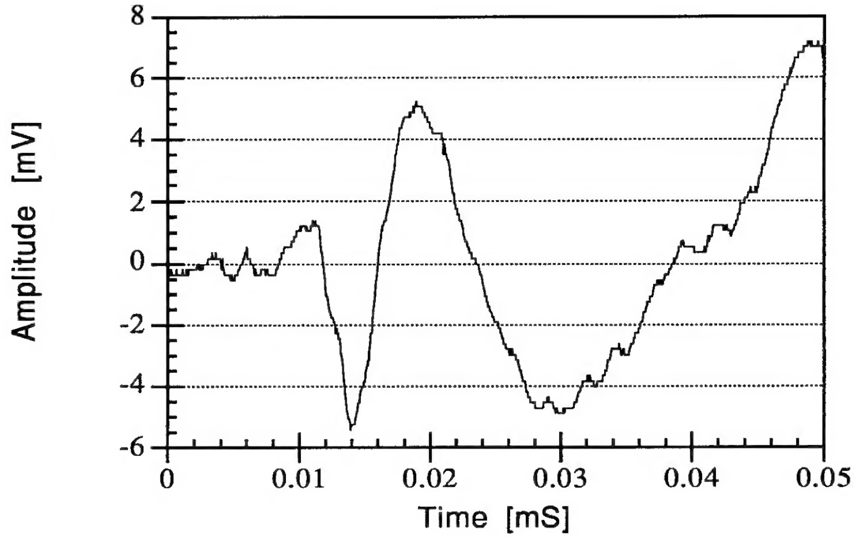

Figure 6: Response of a ceramic/polymer composite surface mounted transducer to a lead break 127mm away on an aluminium thin plate.

Figure 7 shows the response of an embedded transducer to a lead break on the surface of the epoxy plate. It should be noted the difference in time axis from the previous figures. It is believed that the signal from the embedded sensor is a signal generated from an averaging of the acoustic waves present in the epoxy plate. This is due to the large size of the transducer [3cm x 4cm].

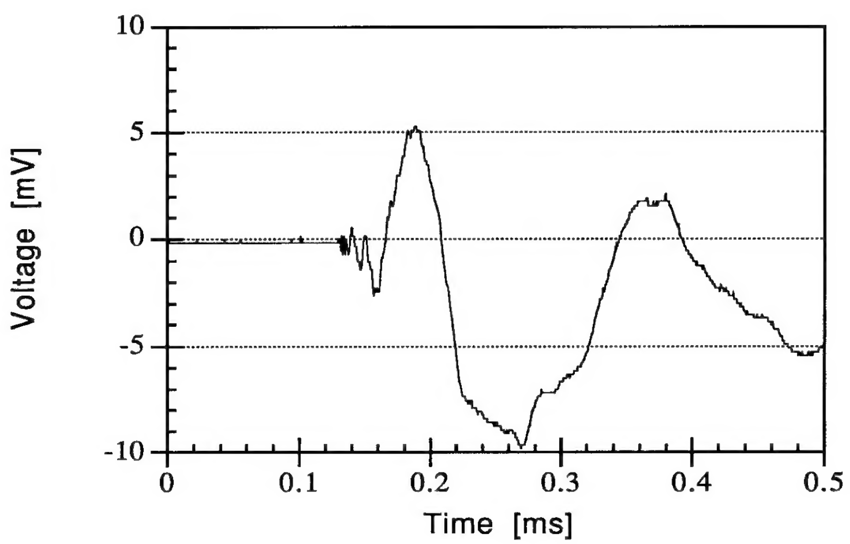

Figure 7: Response of an embedded ceramic/polymer composite transducer to a lead break on the surface of the epoxy plate a distance of 8.5cm from the transducer.

Further work is in progress to improve the ability of the embedded sensor to detect plate waves in composite structures.

5. References

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